Kinetic effects in the turbulent solar wind: capturing ion physics with a Vlasov code

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The problem of the heating of the solar wind plasma represents nowadays a top priority subject in the field of space plasma physics. One of the most puzzling aspects of the dynamics of the interplanetary medium consists in the empirical evidence that the solar wind is hotter than expected as an expanding gas. Scientists pointed out that the explanation of this empirical evidence is related to the turbulent character of the solar wind plasma. Within this physical scenario, the energy injected by the Sun into the Heliosphere as large wavelength fluctuations is channeled towards short scales through a turbulent cascade until it can be transferred to the plasma particles in the form of heat. In this short-wavelength region of the turbulent spectrum kinetic effects govern the system dynamics. Studying these processes with self-consistent kinetic models, in a fully turbulent regime, is today a challenge for scientists. Recent data analyses [1], based on direct solar wind observations from spacecraft, aimed to quantify kinetic effects through the temperature anisotropy on the proton velocity distribution functions (VDFs) with respect to the magnetic field. Values of the anisotropy $T_\perp/T_\parallel$ range broadly, with most values between 10^{-1} and 10. The distribution of $T_\perp/T_\parallel$ depends systematically on the ambient proton parallel beta $\beta_\parallel$, the ratio of parallel kinetic pressure to magnetic pressure, manifesting a characteristic shape in the parameters plane defined by $T_\perp/T_\parallel$ and $\beta_\parallel$. In the present work, kinetic plasma processes have been investigated in the framework of solar wind turbulence, employing Hybrid Vlasov-Maxwell (HVM) simulations [2] in 2D-3V and 3D-3V phase space configurations. In the turbulent regime, kinetic effects manifest through a deformation of the VDFs. These patterns of non-Maxwellian features are concentrated in space nearby regions of strong magnetic activity [3]: the VDFs are modulated by the magnetic topology, and can elongate along or across the local magnetic field. The dependency of $T_\perp/T_\parallel$ on $\beta_\parallel$, commonly observed in spacecraft data, has been recovered using an ensemble of HVM simulations [4]. By varying plasma parameters, such as plasma beta and fluctuation level, the simulations explore distinct regions of the parameter space given by $T_\perp/T_\parallel$ and $\beta_\parallel$, similar to solar wind sub-datasets, and provide results in remarkable quantitative agreement with those recovered from years of observations in the solar wind.

References

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